In Ethiopia, to about 3,300,000 tons of surplus coffee, cotton, wheat and barley residues are produced annually though not all are economically accessible; Even the much-reduced figure of those residues which arise from centralized state-farms, put at about 600,000 tons, is large enough to make a significant contribution to the Ethiopian energy economy. Briquetting is the process of conversion of agricultural waste into uniformly shaped briquettes that are easy to use, transport and store. At present, Coffee husks are an excellent material for briquetting available with 10 percent moisture content. This study aims comparing briquettes produced from coffee husk-molasses and coffee husk-clay, assessing the briquetting of biomass improves its handling characteristics, increases the volumetric calorific value, reduces transportation costs and makes it available for a variety of application and go through assessing the recent binder less briquetting technology.

Keywords: Briquette; Coffee Husk; Molasses; Clay

A project about development of a technology for combustion of coffee pulp from the Swiss Center of Appropriate Technology and Social Ecology CATSE (Okozentrum Langenbruck) had shown in 2010, that combustion of dried coffee pulp cannot be completed successfully in practice, excessive smoke development and early extinction of the fuel result [2]. However, combustion is only feasible under special laboratory conditions.

Depending on the amount of coffee pulp in the husk, this leads to the mentioned uncomplete combustion of coffee husk when the waste piles are set to fire. 6/49 from the mountain rainforest of Kafa region originates the fair-trade and organic certified Kafa wild coffee, sold in Switzerland and Germany. In the Kafa Forest Coffee Farmers’ Cooperative Union, 26 cooperatives are affiliated with approximately 6,000 small farmers. They process and market mainly sun-dried coffee from Kafa Forest. By collecting and selling wild coffee, coffee farmers of Kafa achieve a long-term income from the rainforest. But so far, the residues from the sun-dried coffee production has not been used but is burned in piles in order to get rid of coffee husk waste.

Even the much-reduced figure of those residues which arise from centralized state-farms, put at about 600 000 tons, is large enough to make a significant contribution to the Ethiopian energy economy [3]. Briquetting is the process of conversion of agricultural waste into uniformly shaped briquettes that are easy to use, transport and store. At present, Coffee husks are an excellent material for briquetting available with 10 percent moisture content [4]. Ethiopia heavily biased towards wood consumption, particularly in the household sector. Demand for wood and wood products, particularly charcoal which is the fuel of choice in many urban areas, is often growing and deforestation is a potential problem.

The goal of this study is comparing briquettes produced from coffee husk-molasses and coffee husk-clay, assessing the briquetting of biomass improves its handling characteristics, increases the volumetric calorific value, reduces transportation costs and makes it available for a variety of application and go through assessing the recent binder less briquetting technology [5].
Objectives

General objective

The general objective of the study is comparative evaluation of physio-chemical parameters of coffee husk briquettes by using molasses and clay as a binding agent compressed through piston press.

Specific objectives

The specific objective of this project is just to show the way how briquettes can:

➢ Reduce the potential problems of deforestation in serving as substitute for fuel wood as of it is alternative source renewable energy
➢ Generate information regarding to coffee husk waste-wealth.

![Experimental frame work](image)

Figure 1: Experimental frame work

Raw material storage

The coffee husks are relatively very light with bulk densities ranging from 100 to 140 kg/m³). Because of their bulky nature these are normally stored in the open area. Depending upon the availability of supply, feed material for 6-14 days should be stored.

Sorting/sieving

All unwanted materials or large biomass waste are removed to ensure that all the feedstock is of the required size. Screens may be employed to avoid contamination by extraneous materials like stones and steel pieces etc. and the screen mesh should be based on the largest size of the feed.

Crushing

The coffee husks should be crushed to small pieces to about 5-8 mm size with 10-20% fines so as to enhance their workability and compactness. Hammer mills are employed to reduce the particle size of the feed material. While many types of crushing and grinding equipment are available in the market, for biomass materials, hammer mills are considered the most suitable because of their availability in various sizes.

Pre-heating

The addition of heat benefits by relaxing the inherent fibers in the coffee husks and apparently softening its structure resulting in release of the organic matter bonding or gluing on to the surface. This phenomenon is also known as sweating the biomass.

Mixing

This process is done in situations where you want to use a range of different feedstock to optimize the burning characteristics of the final fuel. For example, biomass materials with high ash content could be mixed with biomass material of low ash content. Biomass with low energy content such as papers can be appropriately mixed with those of high energy content. This helps to attain the right quality (long burning period, non-smoking and odor free) that will make briquettes competitive in the market.

An appropriate binder, molasses and clay are added and mixed with the coffee husk thoroughly. This enhances the compactness of the biomass material and prevents them from falling apart. Water is usually added to the feedstock to make them loose and easy to work on. Some biomass materials require to be soaked in water for two days to ensure that they are soft enough to work on.
Densification

Densification represents a set of technologies for the conversion of biomass into a fuel. The technology is also known as briquetting and it improves the handling characteristics of the materials for transport, storing etc. Finally, the feedstock is compacted by briquetting machine resulting the briquettes those will need to be left to dry.

Sample Preparation

Coffee husk samples were collected and dried to a moisture content of 10%. The coffee husk was then comminuted to a screen size of 3 and 6 mm fitted. The milled husk was graded to different particle sizes by screening through mesh of varying sizes. Moisture content of the graded coffee husk was regulated by adding known quantities of distilled water to the samples followed by mixing and storing in air-tight bags for 48 hours to allow for uniform distribution of the moisture. Different proportions of sugarcane molasses or clay were mixed with coffee husk. The mixture should be well mixed to give a consistent material for compression into briquettes.

Procedures followed

Firstly, 2 kg of coffee husk with 6 mm particle size have been measured. 40% of which was fine particle and then mixed with 900 ml (45%) binding agent (molasses/clay). 1 kg sample were taken and filled in a metal container with cylindrical shape having volume of 0.002 m³. The briquette samples were made by compressing the coffee husk-molasses and coffee husk-clay mixture in a pressing machine. After compression, the sample pushed out of the cylinder. The samples were then dried in a drier at a temperature of 60 ºC. After well dried, the volumes of the briquette samples were measured and similar procedures were followed for smaller sized particles altering with 45% and 25% binding agents.

Experimental Results

The experimental observations are summarized in the Table 1 and 2.

![Table 1: Physico-chemical Properties of Coffee Husk-Molasses briquette](image1)

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Briquette formulation</th>
<th>Property</th>
<th>45% binder Particle size</th>
<th>25% binder Particle size</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>ρ (bulk)(kg/m³)</td>
<td>(6 mm)</td>
<td>(3 mm)</td>
</tr>
<tr>
<td>1</td>
<td>Coffee Husk- Molasses</td>
<td>500</td>
<td>666.7</td>
<td>500</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ρ (after comp.) (kg/m³)</td>
<td>666.7</td>
<td>833.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Binding property</td>
<td>Poor, but better than 25%</td>
<td>Best, but lower than clay</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Combustibility</td>
<td>Very good, but higher than clay</td>
<td>Excellent, lowest smoke of all</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ash content</td>
<td>Highest, but lower than clay</td>
<td>Relatively lower</td>
</tr>
</tbody>
</table>

![Table 2: Physico-chemical Properties of Coffee Husk-Clay briquette](image2)

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Briquette formulation</th>
<th>Property</th>
<th>45% binder Particle size</th>
<th>25% binder Particle size</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>ρ (bulk)(kg/m³)</td>
<td>(6 mm)</td>
<td>(3 mm)</td>
</tr>
<tr>
<td>1</td>
<td>Coffee Husk- Clay</td>
<td>500</td>
<td>666.7</td>
<td>500</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ρ (after comp.) (kg/m³)</td>
<td>714.3</td>
<td>909</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Binding property</td>
<td>Very good, but lower than smaller size</td>
<td>Best of all</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Combustibility</td>
<td>Very good, but lower than molasses.</td>
<td>Excellent, lower than molasses.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ash content</td>
<td>Highest of all</td>
<td>Highest but lower than larger size</td>
</tr>
</tbody>
</table>

Discussion

The density of the larger particle size (6mm) with 45% molasses and clay is found to be 666.7kg/m³ and 714.3 kg/m³ respectively and the densities of the smaller particle size (3mm) with 45% binder are found to be 833.3 kg/m³ and 909 kg/m³ and also for larger and smaller particle size with 25% both binders are found to be 588, 625, 769.2 and 833.3 kg/m³ respectively.
An experimental result indicates that there is no significant difference between the values of the bulk densities of the sample with 25% and 45% of binder. The factors that affected density significantly at constant pressure were found to be binder content and the particle size.

The quantity and type of binder was found to be the most significant factors affecting the density of the briquettes followed by particle size. As the density of the briquette increases the combustibility also increases for the same binding agent.

The experimental result show that the ash content of the briquettes produced by coffee husk-clay is higher than that of coffee husk-molasses. This is why the clay comprises of unburned mater like, sand. Clay has better binding capacity than molasses but what matter is that the lower combustibility and higher ash content.

Material and energy balance for a particular briquetting machine

Previously, employed technologies required binders in the production of briquettes from agro-waste. Here we are going to introduce currently available screw extruder technology, however, use the BINDERLESS technology, which is found to be very economical.

Before a material and energy balance can be carried out, it is first necessary to decide on an operating system to form the basis of the analysis as represented in Figure 2.

A) Feed Processing

The function of this system is to take the feed, process it and make it suitable for the pre-heater. Accordingly, this subsystem comprises sieving, grinding or drying or both (depending upon the raw material) storage and conveying to the feed pre-heater.

B) Pre-heater

The function of this component is to heat the pre-processed feed to the desired temperature by circulating the heat transfer medium and, finally, to convey the preheated material to the briquetting machine. During this stage there is no material loss but some moisture is removed from the feed due to heat gained from the furnace.

Design basis

- Two units of each 750 kg/h (i.e., Feed = 1500 kg/h)
- Working time = 20 hours/day
- Annual working time = 245 days/year
- Heating value of coffee husk = 4200 kcal/kg
- No heat is required for drying coffee husk
- Furnace efficiency = 90%
- Specific heat of coffee husk at 5% moisture = 0.37
- Initial temperature = 30 °C

Material Balance

The overall material balance is given by the following equation:

\[ F - \sum_{i=1}^{3} X_i Y_i = P_n \text{ (kg/hr)} \]

Where, \( F = \text{feed rate with } x_f \text{ moisture content} \)
\( X_1, 2, 3 = \text{moisture loss from components 1, 2 and 3} \)
Y1,2,3 = material loss from components 1, 2 and 3
PC = number of briquettes used in furnace
Pn = net production of briquettes
xf, xf1, xf2, xf3 = moisture content of different streams

**Material balance on feed processing**

Assuming 1% loss of material at (xf)1 moisture content,

\[
\text{Output (F)} = 0.99 (\text{F} - \text{X1}) \quad \text{with (xf)}_1 = 0.1 \quad \text{moisture content}
\]

\[
\text{F1} = 0.99 \times (1500 \text{kg/h - 0}) = 1485 \text{kg/h}
\]

- Loss of material (Y1) = F – F1, with (xf)1 = 0.1 moisture content

\[
Y1 = 1500 \text{kg/h} - 1485 \text{kg/h} = 15 \text{kg/h}
\]

**Material balances on preheating**

In this section the biomass is heated to about 100 °C. About 2% loss of moisture i.e. from 10% to 8% is expected.

- Loss of moisture (X2); F1 = F1 * (xf)1 – (F1 – X2) (xf)2

\[
X2 = \frac{F1 \times (xf)_1 - F1 \times (xf)_2}{0.92}
\]

\[
X2 = \frac{1485 \text{kg/h} \times (0.1) - 1485 \text{kg/h} \times (0.08)}{0.92}
\]

\[
X2 = 32 \text{ kg/h}
\]

Output (F2) = F1 - X2

\[
\text{F2} = 1485 \text{kg/h} - 32 \text{ kg/h}
\]

\[
\text{F2} = 1453 \text{ kg/h}
\]

**Material balance on briquetting and cooling subsystem**

In this subsystem, the moisture is further expected to reduce from 8% to 5% and the direct loss of material is assumed to be 1.1%.

Input (F2) = 1453 kg/h with xf2 = 0.08

- Loss of material due to loss of moisture = (xf)2, F2 - (F2 - X3) (xf)3
Energy Balance

• Direct loss of material (Y3) = 0.011(F2)
  Y3 = 0.011*1453 = 16 kg/h

Output (F3) = F2 – X3 – Y3
  F3 = 1453 kg/h – 46 kg/h – 16 kg/h = 1391 kg/h

Energy Balance

Preheating
The material is heated up to 100 °C and there is loss of moisture from 10% in feed to 8% in the output.

Heat required in pre-heater (Q2) = F1^*Cp (T_f – T_i) + X_2^*h_{fg}
  h_{fg} = h_g – h_l; h_{fg} = 560 kJ/kg

Therefore, Q2 = F_1^* 0.37 (100 – 30) k + X_2^* 560 kJ/kg
  Q2 = 1485 * 0.37(70) + 560 kJ/kg * 32.3 kg/h
  Q2 = 56549.5 kJ/h = 57 MJ/h

Furnace
Assuming 50% heat going for preheating and the remaining 50% accounted for by losses in flue gases (40%) and losses due to radiation in oil circulating system (10%).
Thermal energy output from the furnace

\[ Q_{out} = (Q_1 + Q_2) \]
\[ Q_{out} = 2 \times 56549.5 = 113,099 \text{ kJ/h} \]

Thermal energy input in the furnace, \( (Q_{in}) = \frac{(Q_{out})}{\eta} \)

\[ Q_{in} = 126,656.6 \text{ kJ/h} = 126 \text{ MJ/h} \]

The number of briquettes required in furnace for preheating having heating value of 4200 kcal/kg

\[ Q_{in} = P_c \times CV \quad \text{Where, } CV \quad \text{is calorific value of coffee husk} \]

\[ P_c = \frac{Q_{in}}{CV} = 4.2 \frac{kcal}{kJ} = \left( \frac{125,665.6 \text{ kJ/h}}{4,200 \text{ kcal/kg}} \right) \]

\[ P_c = 126 \text{ kg/h} \]

Net product \( (P_n) = F_3 - P_c \)

\[ P_n = 1391 \text{ kg/h} - 126 \text{ kg/h} \]

\[ P_n = 1265 \text{ kg/h}; \quad \text{Where } P_c \text{ is the number of briquettes used in the furnace.} \]

### Economic analysis

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Description</th>
<th>Quantity</th>
<th>Unit cost (Birr)</th>
<th>Total cost in (Birr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cooling conveyor</td>
<td>1</td>
<td>49,700</td>
<td>49,700</td>
</tr>
<tr>
<td>2</td>
<td>Hammer mill</td>
<td>2</td>
<td>45,200</td>
<td>90,400</td>
</tr>
<tr>
<td>3</td>
<td>Storage bin</td>
<td>1</td>
<td>47,000</td>
<td>47,000</td>
</tr>
<tr>
<td>4</td>
<td>Screw conveyor</td>
<td>2</td>
<td>50,850</td>
<td>101,700</td>
</tr>
<tr>
<td>5</td>
<td>Pre-heater</td>
<td>2</td>
<td>153,900</td>
<td>307,800</td>
</tr>
<tr>
<td>6</td>
<td>Furnace</td>
<td>1</td>
<td>252,950</td>
<td>252,950</td>
</tr>
<tr>
<td>7</td>
<td>Heater</td>
<td>2</td>
<td>175,500</td>
<td>351,000</td>
</tr>
<tr>
<td></td>
<td>Grand total</td>
<td></td>
<td></td>
<td>12,00,350</td>
</tr>
</tbody>
</table>

Source: [http://matche.com](http://matche.com) and [http://alibaba.com](http://alibaba.com)

### Table 3: Estimation of purchased equipment cost

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Description</th>
<th>Units of measurements</th>
<th>Quantity</th>
<th>Unit cost (birr)</th>
<th>Total cost (Birr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cooling conveyor</td>
<td>Tones</td>
<td>7,350</td>
<td>300</td>
<td>22,05,000</td>
</tr>
<tr>
<td>2</td>
<td>PP-bag (100kg)</td>
<td>Pieces</td>
<td>68,159</td>
<td>5</td>
<td>3,40,795</td>
</tr>
<tr>
<td></td>
<td>Grand total</td>
<td></td>
<td></td>
<td></td>
<td>25,45,795</td>
</tr>
</tbody>
</table>

### Utilities

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Description</th>
<th>Req. No.</th>
<th>Salary/month (Birr)</th>
<th>Annual salary (Birr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>General manager</td>
<td>1</td>
<td>3000</td>
<td>36,000</td>
</tr>
<tr>
<td>2</td>
<td>Purchaser and sales person</td>
<td>2</td>
<td>900 * 2</td>
<td>21,600</td>
</tr>
<tr>
<td>3</td>
<td>Accountant</td>
<td>1</td>
<td>1,500</td>
<td>18,000</td>
</tr>
<tr>
<td>4</td>
<td>Secretary</td>
<td>1</td>
<td>1,100</td>
<td>13,200</td>
</tr>
<tr>
<td>5</td>
<td>Production supervisor</td>
<td>3</td>
<td>2000 * 3</td>
<td>72,000</td>
</tr>
<tr>
<td>6</td>
<td>Chemist</td>
<td>1</td>
<td>2,300</td>
<td>27,600</td>
</tr>
<tr>
<td>7</td>
<td>Mechanic</td>
<td>2</td>
<td>1,200 * 2</td>
<td>28,800</td>
</tr>
<tr>
<td>8</td>
<td>Electrician</td>
<td>2</td>
<td>1,200 * 2</td>
<td>28,800</td>
</tr>
<tr>
<td>9</td>
<td>Operator</td>
<td>12</td>
<td>2,300 * 12</td>
<td>331,200</td>
</tr>
<tr>
<td>10</td>
<td>Guard</td>
<td>3</td>
<td>700 * 3</td>
<td>25,200</td>
</tr>
<tr>
<td></td>
<td>Grand Total</td>
<td>28</td>
<td></td>
<td>602,400</td>
</tr>
</tbody>
</table>

Source: [http://matche.com](http://matche.com) and [http://alibaba.com](http://alibaba.com)
Electricity and water are the two major utilities required by the plant. Assuming that 40% water is needed for mixing and for washing and other purposes it is assumed to 60% of the water used for mixing and thus, totally be 4704m$^3$/yr. The unit cost per m$^3$ is 7.00 birr then the total cost for water is 32,928 birr and 117,072 birr/yr for electricity and others. The total annual cost of utilities is estimated at Birr 1,50,000.

**Initial investment cost**

- **T.I.C = W.C + F.C.I**

Purchased equipment cost = 25% of F.C.I = 1,200,550 birr

Therefore, F.C.I = (1,200,550*100)/25 = 4,802,200 birr

T.I.C = 15% of T.I.C + F.C.I

T.I.C = F.C.I/0.85

T.I.C = 4,802,200/0.85

T.I.C = 5,649,647 birr

- **W.C = 15% of T.I.C**

W.C = 0.15 * 5,649,647 = 847,447 birr

- **Depreciation = T.I.C/service life (5 yr)**

= 5,649,647/5 = 1,129,929 birr/yr

<table>
<thead>
<tr>
<th>Items</th>
<th>Cost (birr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw material</td>
<td>2,545,795</td>
</tr>
<tr>
<td>Utilities</td>
<td>150,000</td>
</tr>
<tr>
<td>Labor cost direct</td>
<td>602,400</td>
</tr>
<tr>
<td>Maintenance (2% F.C.I)</td>
<td>96,044</td>
</tr>
<tr>
<td><strong>Total operating cost</strong></td>
<td>3,394,239</td>
</tr>
</tbody>
</table>

**Table 6: Annual production cost**

Profitability analysis

**Annual income**

- We set a unit selling price of briquette is 1500 birr/tonne
- Annual produced briquette = 1265kg/h * 20h/day * 245day/yr = 6,198.5 tonnes/yr Total annual income is found to be 6,198.5 tonnes/yr * 1,500 birr/tonne = 9,297,750 birr/yr

**Profit = annual income – total operating cost – depreciation**

- **Return on investment (R.O.I)**

Yearly profit = 9,297,750 – 3,394,339 – 1,129,929 = 4,773,582 birr/yr

Np = yearly profit (1 – tax rate (ø)) where, ø = 30% = 0.3

Np = 4,773,582 birr/yr (1 – 0.3)

Np = 3,341,507 birr/yr

- **Return on investment (R.O.I)**

(R.O.I) = Np/T. I.C

R.O.I = 3,341,507 / 5,649,647 = 0.59 = 59%

The minimum return on investment (R.O.I) is 15% therefore 59% is greater than the minimum acceptable R.O.I so that, the project is feasible.

- **Payback period (PBP)**

PBP = (F.C.I – Vs) / (Np + depreciation)

PBP = (4,802,200 – 0) / (3,341,507 + 1,129,929)

PBP = 1.07 yr
Reduction in Farmers’ Incomes

The coffee husk briquettes will directly replace wood. Whilst this has important environmental impacts the reduction in the demand for fuel wood will adversely affect farmer’s incomes. Farmers often rely upon tree cutting to supplement incomes particularly at occasions when additional monies are required to pay school fees, medical costs weddings and funerals.

Recommendations

As we went through this study, we can get some points those have to be recommended;

➢ The combustibility of briquettes increases as the density increases but the optimum point has to be further studded.
➢ The project work mainly gives emphasis only for coffee husk but there are plenty of agro- residues those will be convenient for briquette, like maize stocks require study.

References